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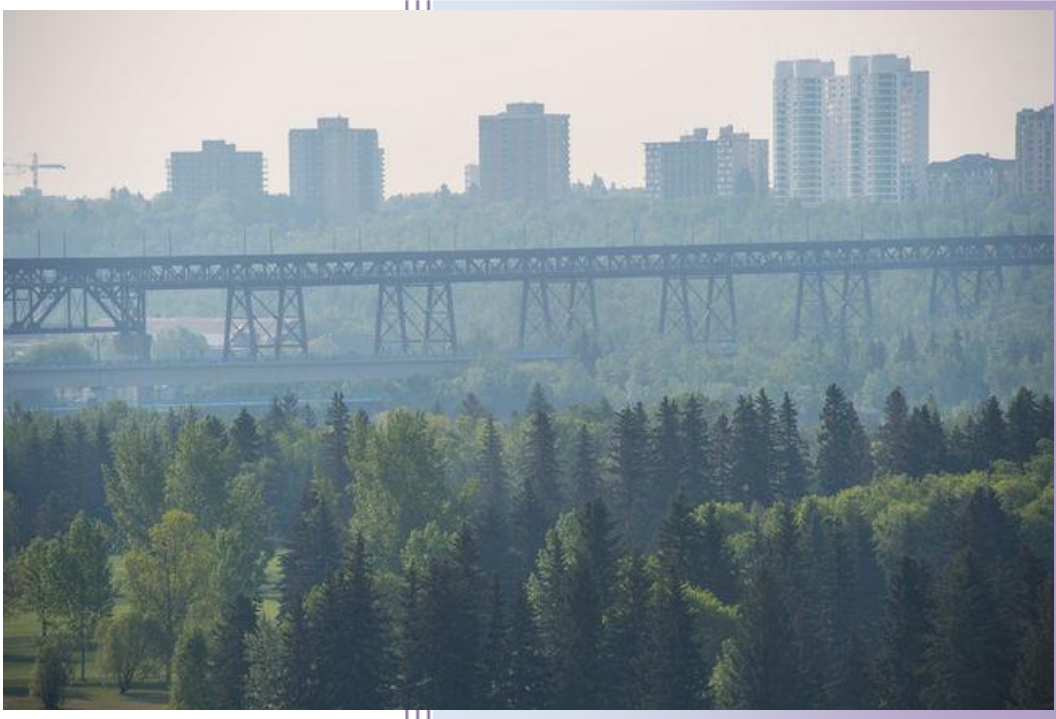
"Air Quality Monitoring of Edmonton's Fine Particulate Matter Response Plan Initiatives"



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Executive Summary

Exposure to ambient fine particulate matter with the diameter less than 2.5 micro-meters (µm) ($PM_{2.5}$) is of increasing public concern over recent decades due to its health-related impacts (e.g. cardiac and respiratory diseases). Recently, there have been questions about ambient $PM_{2.5}$ levels in the Edmonton Central Region (Figure 3.b). Between 2008-2010 and 2009-2011, Alberta Environment and Sustainable Resource Development (AESRD) found that the concentrations of $PM_{2.5}$ in the Alberta Capital Region, which includes the Edmonton Central Region, exceeded the Canada wide standards. Specifically, it was identified that Edmonton Central and Edmonton East ambient air quality monitoring stations within the Capital Region were in Level 4 (Mandatory Plan to Reduce) and two other stations were in Level 3 (Management Plan) of the framework. Accordingly, a response plan has been prepared in 2014 with the goal of reducing ambient $PM_{2.5}$ concentration, and keeping the concentration below Level 4, at all the monitoring stations within the Capital Region. Based on the prepared science report (AESRD, 2014)[1], the investigations narrowed down the factors of increased $PM_{2.5}$ concentration into secondary fine particulate matter formation (from NO_x, SO_2, and VOCs) mainly from electrical generating stations, refineries, petrochemical facilities, and off-road/on-road automobile sources.

In 2012 the City of Edmonton, as part of Alberta Capital Region stakeholders, was notified about the $PM_{2.5}$ exceedances. Additionally, based on the response plan, City of Edmonton is collaborating with stakeholders in order to fulfill the response plan objectives, which are:

- *Management Action*: Identify and develop management actions that can be implemented during event days and throughout the year to achieve measurable reduction in ambient fine particulate matter concentrations. (2015-2017)
- *Investigation*: Continue to improve general and scientific knowledge of fine particulate matter in the capital region for strategic, effective, and efficient management of issue. (2017-2020)
- *Engagement*: Promote outreach, education, and participation of the public and stakeholders about the state of capital region air quality and about their roles and responsibilities to reduce ambient $PM_{2.5}$. (2020+)

The focus of this project is on the first two objectives–*Management Action and Investigation*– by providing recommendations regarding practical methods in order to support the province in implementation and on-going work related to the management plan and improving the current $PM_{2.5}$ monitoring network for Edmonton Central Region.

In order to do so, the first step is evaluating the current $PM_{2.5}$ monitoring network and finding practical methods to supplement the current network to make it more meaningful for PM2.5 monitoring. Accordingly, the following notes could be considered:

- Most of the Edmonton Central Region monitoring stations are *Source-Oriented* stations (type F). To control and manage the local issues, such as public health and the impact of new facilities and regional development, *Residential Population (Type C) and Urban Reference* monitoring stations are required.
- The EPA Guideline for Monitoring Network suggests that for $PM_{2.5}$ monitoring in the Edmonton central region (Population around 900,000) at least 10 monitoring stations are required. Although the majority of Edmonton's population is concentrated in the central region, the number of monitoring stations in this region is four stations.
- Within the Edmonton central region, multiple monitors are clustered in the eastern and central portions of Edmonton, while multiple population centres with more than 2000 residents have no monitoring sites within 10 km.
- Woodcroft and McIntyre stations are located in industrial regions, and the Edmonton Central station is located beside high rise buildings. These three stations are not suitable urban reference air quality monitoring stations.
- The current monitoring network lacks enough suitable data to determine the contribution of the PM2.5 sources through source apportionment, as there is just one PM supersite station, Edmonton McIntyre, within the Edmonton Central Region. Considering that the McIntyre station is located in a light industrial area, there is the possibility that the apportionment results could be affected by the type of industries operating in that region, which might result in biased conclusions.

Considering the limitations of the current monitoring network, it would be helpful to augment the network by locating new monitoring stations or relocating some stations. For this purpose, a comprehensive study is recommended. Mobile monitoring would be an effective option for this purpose with the goals of:

- Finding residential areas that are more exposed to high concentrations of $PM_{2.5}$ within the Edmonton Central Region (hot spots).
- Evaluating the current monitoring stations based on whether or not they are good representatives of the area.
- Finding locations for instalment of new monitoring stations in order to develop a network that could consist of both Type F and Type C monitoring stations.

The following considerations are recommended for the study design of the mobile monitoring:

- The city can be divided into 4 or 5 different residential parts, each with a radius of 5 km and consisting of more than 2000 residents.
- The study should include different sampling periods between morning and evening in order to determine the peak time for the PM concentration.
- The monitoring should be done at the same locations during different seasons.
- The monitoring device should not be placed beside high traffic roads or high rise buildings, and should remain at each location for at least one hour in order to calculate an hourly average.

The next step for improving the $PM_{2.5}$ management plan is to determine the contribution of different sources on $PM_{2.5}$ emissions. Source apportionment is a suitable technique to accomplish this step. For this method, it is required to analyze the PM composition collected at the receptors through elemental analysis and assign the elements to their potential sources. Some studies previously performed the source apportionment on the Edmonton area; however, as previously mentioned the lack of suitable data (one station) and inappropriate location of the receptor (McIntyre) might lead to an inaccurate analysis, which might not be a good representative of the Edmonton Central Region. Consequently, a comprehensive source apportionment study is

recommended in addition to the previous studies in order to provide further information about the $PM_{2.5}$ emission sources contributions. Following notes should be considered for the study design:

- The PM partitioning should be done at different locations within the Edmonton Central Region to avoid influence of specific PM source on the analysis.
- The sampling locations should be primarily the residential areas that are sufficiently far from industrial areas to avoid any bias judgment.
- Both residential areas highly impacted by local sources and regions located in an area representing more regional background conditions should be considered in order to have a more comprehensive analysis.
- Minimum one year of continuous sampling (every three days or every day depending on the limitations) is recommended to collect enough data for the model.
- It should also be considered that sample analysis and running the model require one additional year to be completed.

Background and Motivation

There is an increasing public concern regarding exposure to ambient fine particulate matter ($PM_{2.5}$) due to its health and environmental impacts. $PM_{2.5}$ can be emitted into the atmosphere as primary (directly emitted to the atmosphere) or secondary $PM_{2.5}$ (formed in the atmosphere as a result of reactions between the precursor gases). Nitrogen oxides (NO_x), sulfur dioxide (SO_2), ammonia (NH_3), and volatile organic compounds (VOCs) are the main precursors for formation of secondary $PM_{2.5}$.

The concentration of $PM_{2.5}$ should be assessed annually under the Clean Air Strategic Alliance (CASA) Particulate Matter and Ozone Management Framework using data collected at air monitoring stations within the Alberta Capital Region. Each monitoring station is then assigned an action level based on the concentration of $PM_{2.5}$. The actions levels for $PM_{2.5}$ are shown in Figure 1.

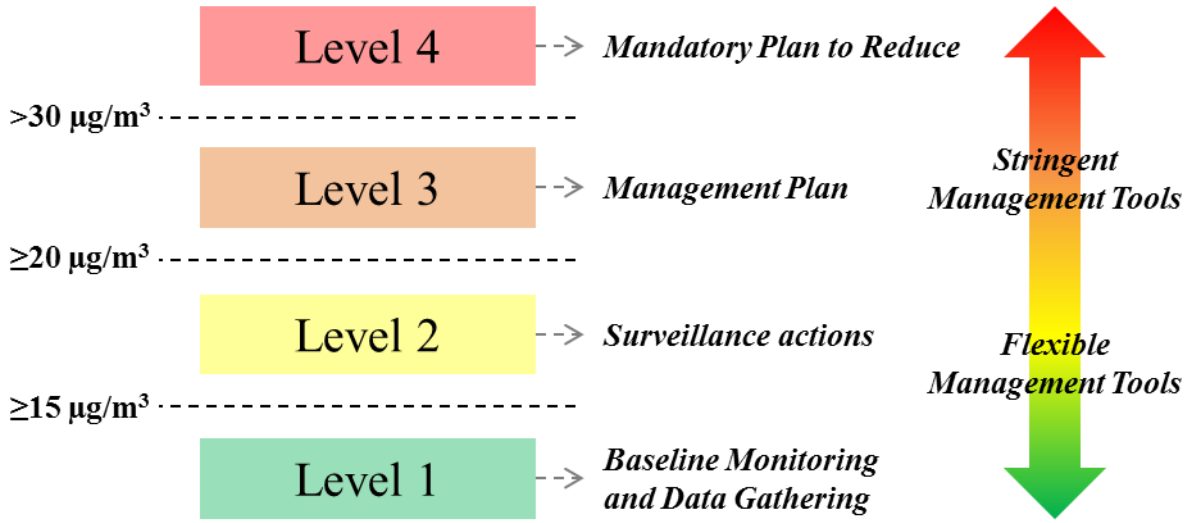


Figure 1. Action Levels and trigger points (thresholds) for $PM_{2.5}$ based on CASA framework which reference the Canada wide standards [2]

Between 2008-2010 and 2009-2011, Alberta Environment and Sustainable Resource Development found that the concentrations of $PM_{2.5}$ in the Alberta Capital Region exceeded the Canada wide standards. Specifically, it was identified that Edmonton Central and Edmonton East ambient air quality monitoring stations within the capital region were in Level 4 (Mandatory

Plan to Reduce) and two other stations were in Level 3 (Management Plan) of the framework. Accordingly, a response plan has been prepared in 2014 with the goal of reducing ambient $PM_{2.5}$ concentrations and keeping the concentrations below Level 4 at all the monitoring stations within the Capital Region. Based on the prepared science report (AESRD, 2014)[1], the investigations narrowed down the factors of increased $PM_{2.5}$ concentration into the secondary fine particulate matter formation (NO_x, SO_2, and VOCs) mainly emitted from electrical generating stations, refineries, petrochemical facilities, and off-road/on-road automobile sources. The investigation approaches that have been taken by the Technical Sub-committee to develop the response include:[1]

- Analysis of historical data:
    - ✓ Seasonal variation of fine PM events
    - ✓ Year-to-year variation of fine PM events
    - ✓ Meteorological Conditions during fine PM events
    - ✓ Mass composition of fine PM events
- Design and deployment of supplemental speciation monitoring
- Implementation of the United States Environmental Protection Agency's Community Multi-Scale Air Quality Model (CMAQ) as a fine PM source apportionment tool.

In 2012, the City of Edmonton, as part of Alberta Capital Region stakeholders, was notified about the $PM_{2.5}$ exceedances. Additionally, based on the response plan, the City of Edmonton is collaborating with stakeholders in order to fulfill the response plan objectives, which are:[1]

- *Management Action*: Identify and develop management actions that can be implemented during event days and throughout the year to achieve measurable reduction in ambient fine particulate matter concentrations. (2015-2017)
- *Investigation*: Continue to improve general and scientific knowledge of fine particulate matter in the capital region for strategic, effective, and efficient management of issue. (2017-2020)

- *Engagement*: Promote outreach, education, and participation of the public and stakeholders about the state of capital region air quality and about their roles and responsibilities to reduce ambient $PM_{2.5}$. (2020+)

The focus of this project is on the first two objectives–*Management Action and Investigation*– by providing recommendations regarding practical methods in order to support the province in implementing and on-going work related to the management plan and improving the current $PM_{2.5}$ monitoring network for the Edmonton Central Region.

While the response plan provided useful information regarding the $PM_{2.5}$ issue, the recent changes in the $PM_{2.5}$ standards and monitoring technology affected the analysis that has been done in the science report. Specifically, in 2015 the new Canadian Ambient Air Quality Standards (CAAQS) were implemented instead of the Canada-wide standards in Alberta. The response plan has been developed based on the previous CAAQS ($PM_{2.5}$ for 24hr: 30 µg/m3), however, new standards ($PM_{2.5}$ for 24hr: 28 µg/m3, $PM_{2.5}$ Annual: 10µg/m3) are more stringent. Therefore, additional actions might be required in order to meet the new standards. Based on the new standards, the reported concentrations for $PM_{2.5}$ on 2010-2012 are even worse since three stations in central regions were now exceeded into level 4.[3]

Furthermore, since 2009 the $PM_{2.5}$ monitoring stations started to implement a new monitoring technology. In 2014 all the monitoring stations within the Edmonton Central Region have been equipped with the new technology. The new technology more effectively accounts for the volatile components in measurements of $PM_{2.5}$ concentration, which results in higher, but more representative measurements. As a result, a step change in the concentration of $PM_{2.5}$ was observed after implementation of the new technology (Figure 2). Since the response plan was prepared based on the previous monitoring technology, additional studies might be required to evaluate the effect of the new technology on the reported $PM_{2.5}$ concentration, especially in the case of historical data analysis.[3]

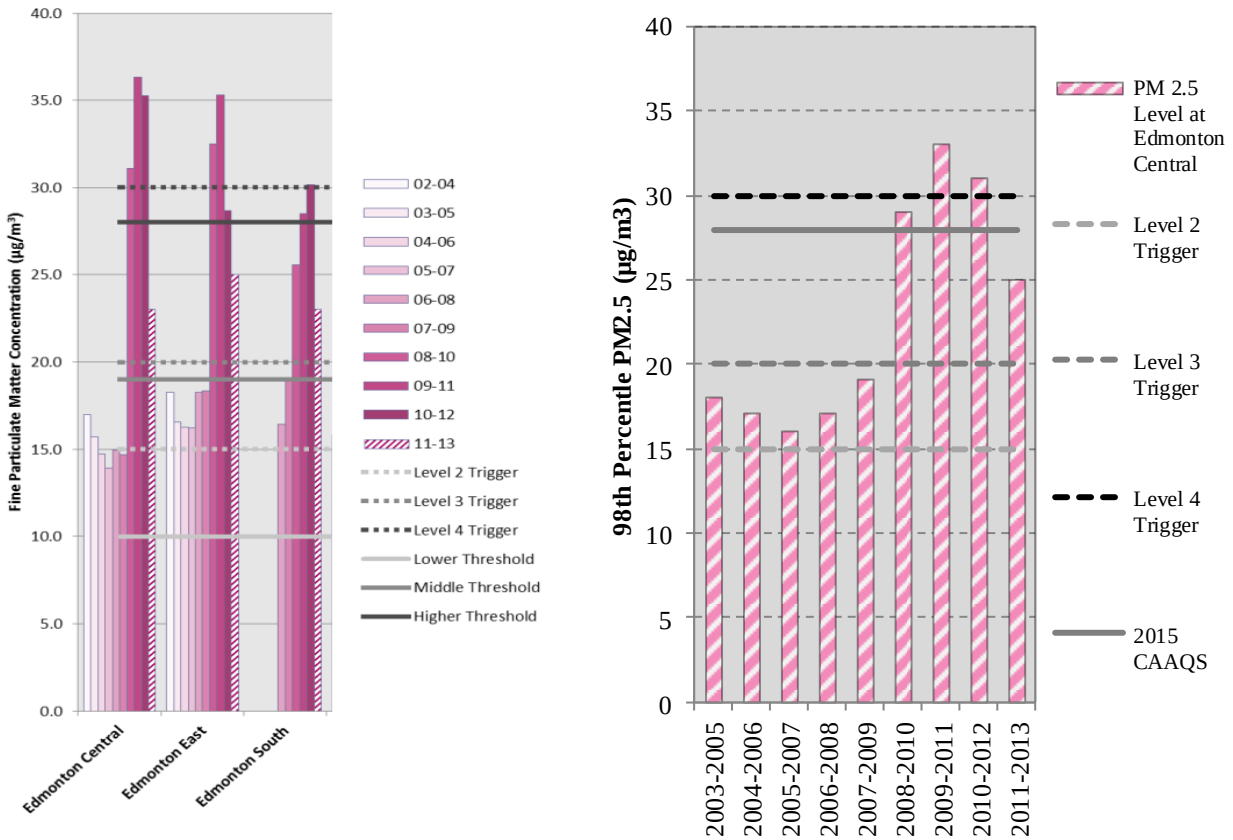


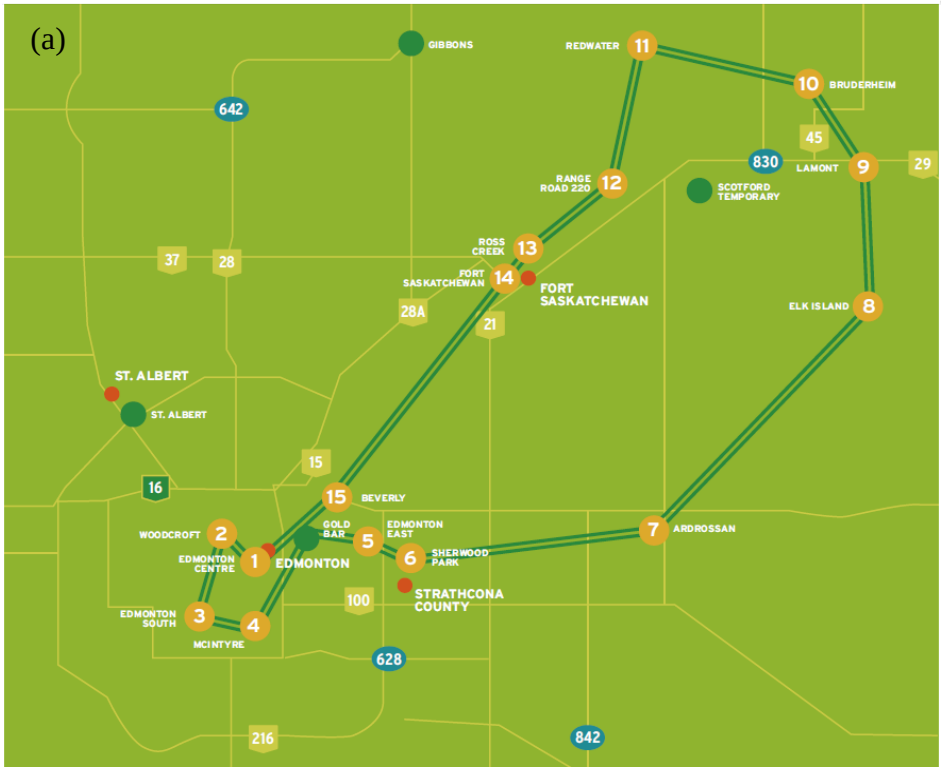
Figure 2. $PM_{2.5}$ concentration comparison between different years ((a) adopted from Capital Region 2014 Air Quality Report (2016)[3] and (b) adopted from M.A. Bari and W.B. Kindzierski (2016)[4])

Edmonton Central Region Monitoring Network

The first step is to evaluate the current monitoring network, so that the City of Edmonton can understand where to support the Provincial Government in building on the management plan for controlling $PM_{2.5}$ concentrations. Figure 3 shows the map of monitoring stations within the Edmonton area. As indicated in the figure there are 15 stations located in the Edmonton area; however, just 6 of these stations are located within the Edmonton Central Region. The United States (US) Environmental Protection Agency's (EPA) guideline for Monitoring Network suggested that for $PM_{2.5}$ monitoring in the Edmonton Central Region (population around 900,000) at least 10 monitoring stations are required. Furthermore, of all the monitoring stations just one station (Edmonton McIntyre) is a PM supersite and can be used for detailed study of $PM_{2.5}$ emissions.

Additionally, to control and manage the local issues, such as public health and the impact of new facilities and regional development, Residential Population (Type C) and Urban Reference monitoring stations (air quality/meteorological monitoring station located within an urban area but not near sources of pollution or obstructions to the wind) are required. The current ambient air quality monitoring plays a role in triggering air quality management activities and assessing the efficacy of those activities (i.e. "Source-oriented" type F monitoring sites). Considering the aforementioned information, the following notes might be helpful for improving the current network:

- Lack of *Residential Population (Type C)* and *Urban Reference* monitoring stations (see Table 1 for definitions).
- Although the majority of the Edmonton population is concentrated in the central region, the number of monitoring stations in this region is four stations (compared to 10 stations recommended by US EPA).
- Within the Edmonton central region, multiple monitors are clustered in the eastern and central portions of Edmonton, while multiple population centres with more than 2000 residents have no monitoring sites within 10 km.



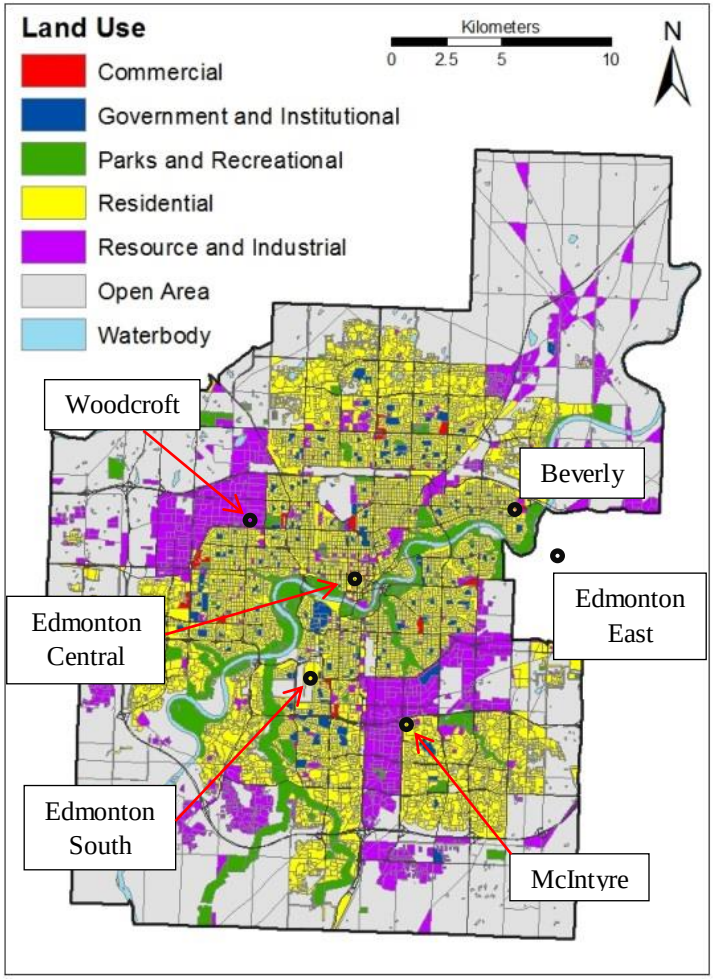


Figure 3. (a) Edmonton monitoring stations map (adopted from Air Quality Monitoring Stations in The Alberta Capital Airshed & Fort Air Partnership (2015)[5] and (b) Edmonton Central region monitoring stations (Adopted from Miller (2012)[6])

Table 1. Different type of air quality monitoring stations [7]

Station type	Description
Types A	*Downtown pedestrian exposure station*. Locate station in the central business district of the urban area on a congested, downtown street surrounded by buildings (i.e. a "canyon" type street) and having many pedestrians. Average daily travel on the street should exceed 1000 vehicle/day, with average speeds of less than 6.7 m/s. Monitoring probe is to be located 0.5 m from the curb at a height of 3±0.5m.
Type B	*Downtown neighborhood exposure station*. Locate station in the central business district of the urban area but not close to any major streets. Specifically, no street with average daily travel exceeding 500 vehicles/day should be closer than 100m from the monitoring station. Typical locations are parks, malls, or landscaped areas having no traffic. Probe height is to be 3±0.5m above the ground surface.
Type C	*Residential population exposure station*. Locate station in the midst of a residential or suburban area but not in the central business district. Station should be more than 100m from any street having a traffic volume in excess of 500 vehicles/day. Station probe height must be 3±0.5m.
Type D	*Mesoscale station*. Locate station in the urban area at appropriate height to gather meteorological and air quality data at upper elevations. The purpose of this station is not to monitor human exposure but to gather trend data and meteorological data at various heights. Typical locations are tall buildings and broadcasting towers. The height of the probe, along with the nature of the stations location, must be carefully documented in each case.
Type E	*Non-urban station*. Locate station in a remote, non-urban area having no traffic and no industrial activity. The purpose of this station is to monitor for trend analyses, for non-degradation assessments, and for large-scale geographical surveys. The location or height must not be changed during the period over which the trend is examined. The height of the probe must be documented in each case. A suitable height is 3±0.5m.
Type F	*Specialized source survey station*. Locate station very near a particular air pollution source under scrutiny. The purpose of the station is to determine the impact on air quality, at specified locations, of a particular emission source of interest. Station probe height should be 3±0.5 m unless special considerations of the survey require a non-uniform height.

- Based on Figure 3, Woodcroft and McIntyre stations are located in the industrial regions. Also, considering the Edmonton Central station is located beside high rise buildings, these three stations are neither suitable Type C nor Urban Reference monitoring stations.
- Network coverage is overly focused on facility emissions at the expense of spatial coverage and population representativeness, which leads to poor north-south coverage for the monitoring network. This may result in maximum concentrations not being recorded during high concentration events. This poor coverage reduces appropriate population representativeness and spatial coverage.
- The current monitoring network lacks enough suitable data to determine the contribution of the sources through source apportionment, as there is just one PM supersite station, Edmonton McIntyre, in the Edmonton Central Region. Considering that the McIntyre station is located in a light industrial area, there is the possibility that the apportionment results could be affected by the type of industries operating in that region, which might result in biased conclusions.

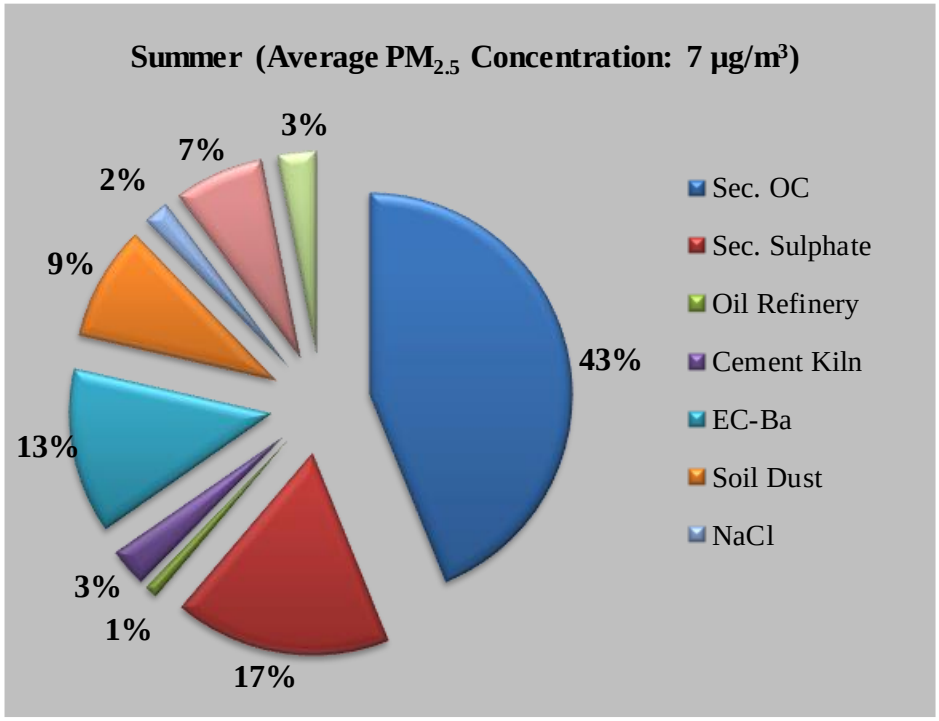
$PM_{2.5}$ Source Apportionment

An important step for implementing the management plan is to find out the contribution of different sources on the $PM_{2.5}$ emission. Source apportionment is a suitable technique to accomplish this step. For this method, it is required to analyze the PM composition collected at the receptors through elemental analysis and assign the elements to the potential sources. In this case, the receptor should be a PM supersite in order to allow the speciation of the collected PM. In addition to determining the contribution of sources, this technique can be used to identify the sources that contributed more to the change in the $PM_{2.5}$ trend. Previously, some source apportionment studies have been done on the Edmonton $PM_{2.5}$ data under the supervision of the Provincial Government.

The first study was done by the University of Toronto on data collected at Edmonton McIntyre station between May 2006-Jan 2008 (Figure 4)[8]. Positive Matrix Factorization (PMF) was used to identify local and long-range sources and determine their contribution to $PM_{2.5}$ mass concentrations. Sampling was done every third day on the Edmonton McIntyre station. Their findings can be summarized as follow:

- A statistically significant winter-high trend was found in Edmonton, indicating distinct seasonality in $PM_{2.5}$ chemical compositions.
- In Edmonton, the relatively lower summertime $PM_{2.5}$ was likely due to the lower contribution of sulphate in summer months as well as strong nitrate formation in winter.
- Factors in Edmonton:
    1. Secondary Sulphate: Sulphate and ammonium, the second largest sources in Edmonton (19% of PM mass concentration), were higher in winter due to the increased consumption of fossil fuels for winter heating under stagnant conditions and low inversions during the winter. The strong dependence of VOCs with the sulphate factor supports the suggestion that the sulphate factor in Edmonton is more related to local contributions than regional factors.

2. Steel Making: calcium (Ca), magnesium (Mg), potassium (K), strontium (Sr), titanium (Ti), and barium (Ba), have higher contributions on weekdays compared to weekends, mostly contributed from outside Alberta.
3. Soil Dust: Ca, Mg, K, Sr, Ti, and Ba, have higher contributions on weekdays compared to weekends, contributed primarily from outside Alberta.
4. Cement Kiln: metal industry-related species, resulted in higher differences between weekdays and weekends, suggesting the contribution of local anthropogenic sources.
5. Salt: sodium (Na) and chlorine (Cl), a significant winter-high pattern was observed, accounting for 2% of the concentration, in the directions of nearby Highway 14 and Highway 2.
6. Traffic Emissions: elemental carbon (EC) 2, EC3, Ba, formate, and copper (Cu), account for 13% of $PM_{2.5}$ concentration.
7. Secondary Organic Aerosol: oxalate, formate, pyrolyzed organic carbon (OP), organic carbon (OCs), ECs, sulphate and iron (Fe), contributed 16% to the $PM_{2.5}$, with a strong summer-high trend, contributed by biogenic and secondary organic aerosol precursor emissions.
8. Secondary Nitrate: nitrate and ammonium, was the largest source accounting for 22%, from local oil refinery emissions that cause regional emissions.
9. Biomass Burning: K, OCs, OP, ECs, oxalate, formate, and Cl, contributions of these were high on weekends in winter; the main source could potentially be wood burning for winter residential heating. During summer a higher contribution was found during the weekdays due to high traffic.



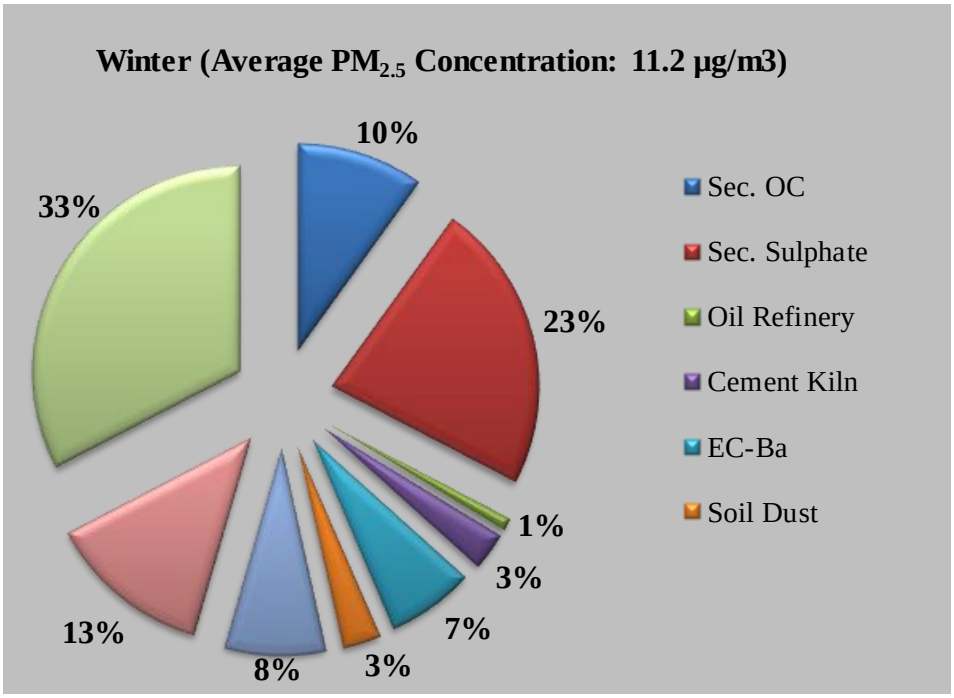
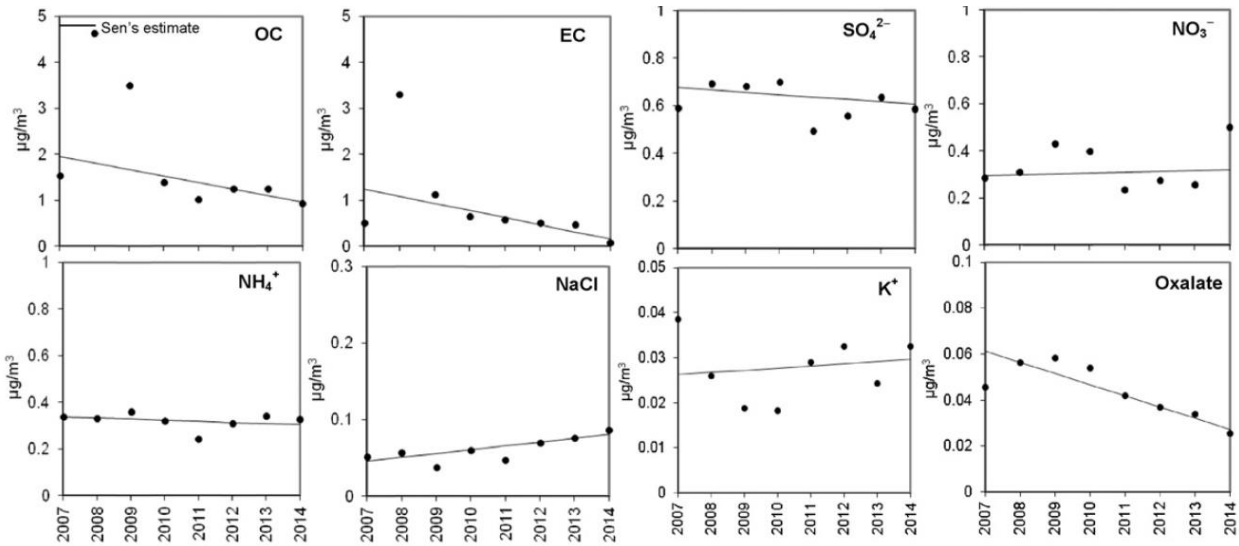


Figure 4. Contributions of different sources on $PM_{2.5}$ emission (adopted from G. Evans and C. Jeong (2015)[8])

The second was done at the University of Alberta, using the data collected from the Edmonton McIntyre station during 2007-2014 (Figure 5) [9]. The study was focused to find the trends in chemical components of $PM_{2.5}$. The same methods as the previous study were used for source apportionment. Throughout the study they concluded that:

- No statistically significant change was observed for ambient $PM_{2.5}$ concentrations over the period of 2007–2014, while significant decreasing trends were found for organic carbon, elemental carbon, oxalate, barium, lead and cadmium.
- A statistically significant increasing trend was observed for sodium chloride indicating an increase of de-icing salt contribution for winter road maintenance in recent years.
- Wood smoke was found as a potential source of $PM_{2.5}$ in Edmonton and the surrounding regions. Further research of the wood smoke contribution to the Alberta Capital Region winter air quality is recommended.
- Notwithstanding the robust population growth that has occurred in Edmonton, these findings reveal that particulate air quality and corresponding trace elements in Edmonton's air has been unchanged or improved over the investigated period (2007–2014).



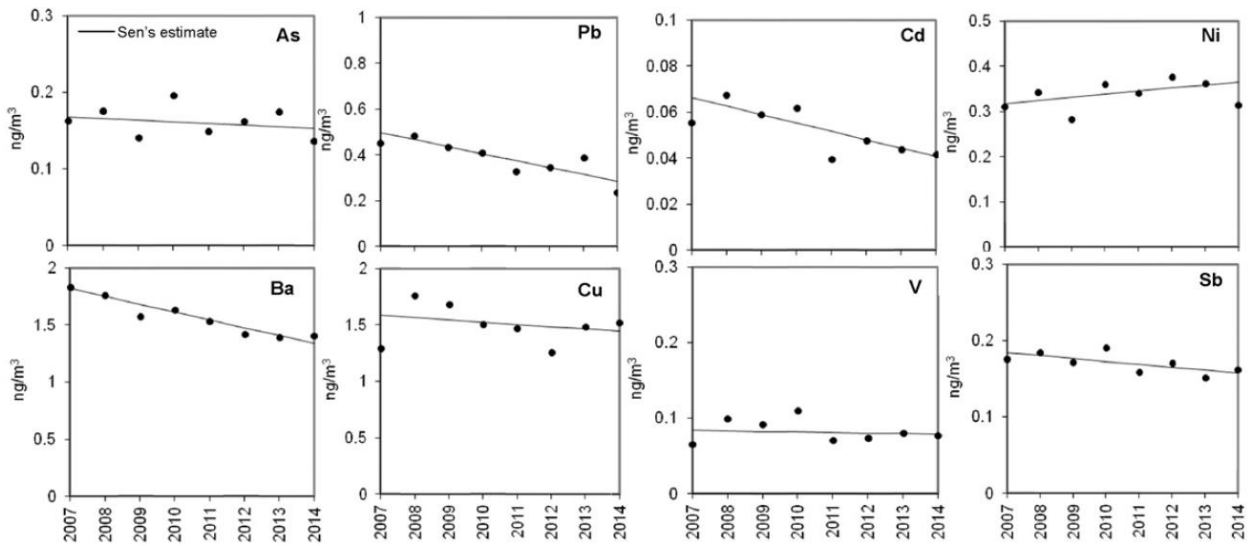


Figure 5. Temporal trends in annual geometric mean concentrations of selected trace components for 2007–2014 at Edmonton McIntyre (adopted from M.A. Bari and W.B. Kindzierski (2016)[9])

While previous studies have been investigating the source apportionments on the Edmonton $PM_{2.5}$ emissions, there have been some factors that could influence the results of their analysis; therefore, there might be opportunities for the City of Edmonton to support their work by considering: (a) The current monitoring network is lacking enough suitable data to determine the contribution of the sources through source apportionment, as there is just one PM supersite station, Edmonton McIntyre, within Edmonton Central Region. (b) Edmonton McIntyre station is located in a light industrial area, so there is potential that the apportionment results could be affected by the type of industries operated in that region, which might result in biased conclusions.

Recommendations

To support Provincial efforts to improve knowledge of the $PM_{2.5}$ issue and implement the management plan, the City of Edmonton could consider a one year mobile monitoring study.. The goals of the mobile monitoring study can be:

1. Finding residential areas that are more exposed to high concentrations of PM within the city (hot spots);
2. Evaluating the current monitoring stations based on whether or not they are good representatives of the area; or
3. Finding the locations for instalment of new monitoring stations in order to develop a network that could consist of both Type F and Type C monitoring stations.

For the mobile monitoring the, following considerations could be helpful:

- The city can be divided into 4 or 5 different residential parts each with a radius of 5km, which consists of more than 2000 residents.
- The study should include different sampling periods between morning and evening in order to find the peak times for the PM concentration.
- The monitoring should be done at the same locations during different seasons.
- The monitoring device should not be placed beside high traffic roads or high rise buildings, and should remain at the location for at least one hour in order to calculate an hourly average.

Based on the first objective of the response plan "identify and develop management actions", a comprehensive source apportionment study is suggested to support the Provincial efforts in identifying the contribution of each source and implementing the management actions. In order to remove the factor that affects previous studies, the following notes should be considered:

- ✓ The PM partitioning should be done at different locations within the Edmonton central region to avoid influence of a specific PM source on the analysis.

- ✓ The sampling locations should be primarily in residential areas sufficiently far from an industrial area to avoid any bias judgment.
- ✓ Both residential areas highly impacted by local sources and regions located in an area that represents more regional background conditions should be considered in order to have a comprehensive analysis.
- ✓ Minimum one year of continuous sampling (every three days or every day depending on the limitations) is recommended to collect enough data for the model.
- ✓ It should also be considered that the analysis of samples and running the model require one additional year to be completed.

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